PATENT SPECIFICATION

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(54) OPTICAL FIBRE TRANSDUCER

(71) We, STANDARD TELEPHONES AND CABLES LIMITED, a British Company, of 190 Strand, London, W.C.2., England, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to the manufacture of optical fibre transformation sections comprising lengths of optical fibre, the two ends of such a length having core cross sections which differ either in size or shape, or in size and shape.

In the design of optical transmission systems it is often necessary to provide a large number of couplings between pairs of optical fibres or between optical fibres and other optical components such as sources and detectors. Some of these couplings are liable to require the use of an optical fibre transformation section for redistributing the optical energy across the optical wavefront leaving one of the optical components in order to match it for launching into the other. This invention is concerned with the manufacture of such transformation sections repeatably and reproduceably in quantity.

According to the invention there is provided a method of making optical fibre transformation sections including the steps of forming an optical fibre preform whose core has longitudinal periodic structure in its refractive index profile, of drawing the preform down to reduce its cross-section, and of parting the drawn preform at intervals along its length to produce optical fibre transformation sections the two ends of each of which have core cross sections which differ either in size or shape, or in size and shape.

A number of methods of making optical fibre transformation sections embodying the invention in preferred forms will now be described with reference to the accompanying drawings in which:—

Figures 1*a*, 1*b*, 1*c*, 1*d* and 2 depict preforms of circular cross section made from nesting alternately higher and lower refractive index components fitted in a tube,

Figures 3*a*, 3*b* and 3*c* depict preforms whose cores are made from spheres fitted in a tube,

Figures 4*a* and 4*b* depict preform cores made from fibre bundles,

Figures 5*a*, 5*b*, and 5*c* depict preforms of rectangular cross sections,

Figure 5*d* depicts a single optical fibre transformation section of rectangular cross section,

Figure 5*e* depicts the transformation section of Figure 5*d* after its cross-sectional shape has been converted from rectangular to circular.

Figure 6 depicts a preform whose core has been created by ion exchange or irradiation,

Figure 7*a* depicts an alternative construction of preform whose core has been created by ion exchange.

Figure 7*b* depicts a component part of the preform of Figure 7*a*, and

Figures 8*a* and 8*b* depict alternative arrangements of a double bushing from which may be drawn optical fibres or fibre preforms having a longitudinal periodic structure in their core profiles.

The first method to be described of making optical fibre transformation sections involves forming a preform comprising a stack of nesting alternately higher and lower refractive index glass components in the bore of a lower refractive index glass tube. Figures 1*a*, 1*b*, 1*c* and 1*d* illustrate four different geometries of stacking components. The higher and lower refractive index components, which are designated A and B respectively, are stacked in a tube C made of the lower refractive index material. The stacking elements are all solids of revolution to provide circular symmetry.

The requisite dimensions of the stacking elements can be readily obtained remembering that during a drawing down operation the volume remains unchanged and hence the product of the square of the bore diameter d and the stacking element interval *t* is invariant. Thus, for instance, if the drawn fibre is to have a core diameter of 100

μm and a periodicity of 100 mm, the initial interval t of the preform would be 1 mm for a 1 mm diameter bore, 100 μm for a 3 mm diameter bore, and so on.

The assembly of the stack of elements inside the tube C is heated and drawn using conventional rod-in-tube optical fibre drawing techniques. It may be noted that this drawing down is liable to trap a relatively large number scattering centres at the interfaces between components. This may produce attenuations of the order of 1000 dB/km which would normally be quite unacceptable for a long distance transmission medium but can be tolerated in short length fibre transformation sections at the ends of a high transmissivity optical fibre.

The positions at which the drawn fibre needs to be parted is determined by visual inspection. Inspection may be facilitated by immersing the drawn fibre in an index-matching liquid.

With the stacking arrangements of Figure 1 the ratio of the core cross-sections at the two ends of a transformation section is a function of its length. For some applications it is desirable to make this cross-section ratio a constant over a small range of lengths. This may be achieved by adopting the structure of Figure 2. In this structure the higher and lower refractive index stacking components A and B are short tubes assembled on a rod E made of the higher refractive index material inside the tube C made of the lower refractive index material. The higher and lower refractive index stacking components A and B are made from materials that will readily interdiffuse. The assembly is fused together and drawn down in the same way as the assemblies of Figure 1. In the drawn fibre there will not be abrupt changes in effective core diameter because of the effects of interdiffusion in the axial direction between adjacent stacking elements. There will however be substantial regions between successive interdiffusion zones where the effective core diameter remains sensibly constant.

It is not necessary for the tube C to be filled with a stack of nesting components so long as air does not become trapped when the assembly is fused together. A particulary simple construction of stack is illustrated in Figure 3. Here the stack is formed exclusively of the higher refractive index elements, which in this instance are spheres G. In the course of drawing these spheres become converted into prolate spheroids G' as depicted in Figure 3b. As an alternative to first forming the stack of spheres and then collapsing the tube aroud them, the spheres can be dropped into the tube one at a time as it is being collapsed as shown in Figure 3c.

Another type of transformation section involves an equal area transformation instead of a taper. Such a transformation section may have a high refractive index material formed from a single rod or an assembly of fibres as depicted in Figure 4a or 4b. The bundle of fibres, which may be clad or unclad, is given a periodic structure in its shaping, for instance by laying up in a jig or by drawing the bundle through apparatus which deforms the bundle by squashing it at periodic intervals. The periodic shaping is retained with adhesive or by heat treatment to fuse the fibres together. The structure is then potted in a lower melting point lower refractive index cladding, or is placed in the bore of a cladding tube of such material which is heated and collapsed around the structure to form a preform. The preform is drawn and cut into appropriate lengths as described previously. The cutting into lengths is facilitated if the initial lay incorporates a dwell region of constant cross-sectional configuration at the regions where the cuts are to be made.

Figures 5a, 5b and 5c depict examples of preforms which may be employed to make prismatic transformation sections instead of ones having circular symmetry.

The preforms of Figures 5a and 5b correspond to those of Figures 1a and 1c respectively, and are assembled by forming a stack of higher refractive index prismatic elements A with intervening lower refractive indxex ones B. The sheath H surrounding the stack is a square section tube whose walls may be components which are fused together at the same time as the elements of the stack are fused together.

The preform of Figure 5c is formed in a different way. A set of ribs is ruled, etched or pressed in the central region of one major surface of a strip J of lower refractive index material. The indentations so formed are then filled with a higher refractive index glass K which is either poured on or applied in the form of frit which is subsequently fused. The higher refractive index glass K is next covered with a lower refractive index layer L, and then the assembly is drawn down and cut into lengths. The cross-sectional shape of a transformation section can be maintained as represented in Figure 5d, or it can be circularized as represented in Figure 5e. (For illustrative convenience only these transformation sections have been depicted as bent round in a semicircle.)

A form of transformation section similar in shape to that of Figure 5d can also be formed in sets by drawing down and cutting into lengths a preform of the type depicted

in Figure 6. Here the surface of sheet of lower refractive index glass M is masked and then apertures are opened in the masking to expose underlying regions N which are converted to higher refractive index regions P by irradiation or an ion exchange reaction. The preform is completed by fusing a second lower refractive index sheet Q to the top surface of the first one.

Selective masking R and then irradiation or ion exchange can also be used to create higher refractive index zones S in glass discs T (Figure 7*a*). The masking is removed, next the disc assembled in a low refractive index tube C (Figure 7*b*), and then the assembly is fused together to form a preform which can be subsequently drawn down and cut into appropriate lengths.

A further method of making optical fibre transformation sections will now be described with reference to Figures 8*a* and 8*b*. An inner bushing U containing a melt of higher refractive index core glass V is located centrally in an outer bushing W containing a melt of lower refractive index cladding glass X. The core/cladding diameter ratio of fibre drawn from the bushings depends upon the relative positions of the two nozzles Y and Z and upon the hydrostatic pressure and resistance to flow at these nozzles. Accordingly an optical fibre can be made with a periodic structure in its core/cladding diameter ratio by cyclically varying the relative pressure applied to the surface of the two melts V and X.

When the two nozzles are level, as depicted in Figure 8*a* and the inner melt V is subjected to variations in applied pressure the total glass flow follows the variations in pressure with the result that external diameter of the drawn fibre fluctuates. When the inner nozzle Y is retracted, as depicted in Figure 8*b* the total glass flow is controlled by the flow resistance of the outer nozzle and is relatively insensitive to the core glass pressure provided that the viscosities of the two glasses are similar. Under these circumstances therefore it is possible to vary cyclically the pressure applied to the inner melt V to produce a fibre with a periodic structure in its core diameter, while retaining a substantially uniform external diameter of the cladding. The cutting of the fibre into lengths corresponding to individual transformation sections may conveniently be synchronised with the means controlling the pressure cycle applied to the core glass melt.

WHAT WE CLAIM IS:—

1. A method of making optical fibre transformation sections including the steps of forming an optical fibre preform whose core has a longitudinal periodic structure in its refractive index profile, of drawing the preform down to reduce its cross-section, and of parting the drawn preform at intervals along its length to produce optical fibre transformation sections the two ends of each of which have core cross sections which differ either in size or shape, or in size and shape.

2. A method as claimed in claim 1 wherein the preform core is made by fusing together a stack of higher refractive index components nested with other components of lower refractive index.

3. A method as claimed in claim 2 wherein said components have circular symmetry.

4. A method as claimed in claim 2 wherein said components are prismatic.

5. A method as claimed in claim 1 wherein the preform core is made by fusing together a stack of elements selected portions of which have had their refractive index modified by irradiation or ion exchange.

6. A method as claimed in claim 1 wherein the preform core is formed by forming a stack of higher refractive index components in a sheath of lower refractive index and wherein the sheath is collapsed around the components and fused thereto.

7. A method as claimed in claim 1 wherein the preform core is formed by drawing down and collapsing the bore of a lower refractive index tube while introducing higher refractive index components into the bore at regular intervals.

8. A method as claimed in claim 1 wherein the preform core is made from a higher refractive index rod which is deformed at regular intervals along its length and wherein a lower refractive index tube is collapsed around the deformed rod and fused thereto.

9. A method as claimed in claim 1 wherein the preform core is made from a plurality of higher refractive index fibres which are laid up in a lay which changes repetitively between two different cross-sectional configurations, wherein the lay configuration of the fibres is secured by bonding them together and wherein a lower refractive index tube is collapsed around the bonded fibres and fused thereto.

10. A method as claimed in claim 1 wherein the preform core is made by forming a periodic indentation pattern in one surface of a lower refractive index strip, by filling said indentations with a higher refractive index material and then covering the filled indentations with a second lower refractive index strip.

11. A method as claimed in claim 1 wherein the preform core is made by selective masking one surface of a glass strip treating the unmasked portions of the strip by ion exchange or irradiation so as to increase the refractive index of those portions, and wherein the portions of increased

refractive index are covered with a second glass strip of lower refractive index.

12. A method as claimed in claim 1 wherein the preform is drawn from a double bushing containing an inner melt of higher refractive index core glass within an outer melt of lower refractive index cladding glass and wherein the relative pressure applied to the two melts is cyclically varied.

13. A method as claimed in claim 12 wherein the pressure applied to the outer melt is not varied.

14. A method as claimed in claim 11 or 12 wherein the nozzle of the inner bushing is upstream of the nozzle of the outer bushing.

15. A method substantially as hereinbefore described with reference to any one of the accompanying drawings of making a set of optical fibre transducers.

16. An optical fibre transformation section made by the method claimed in any preceding claim.

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For the Applicants.

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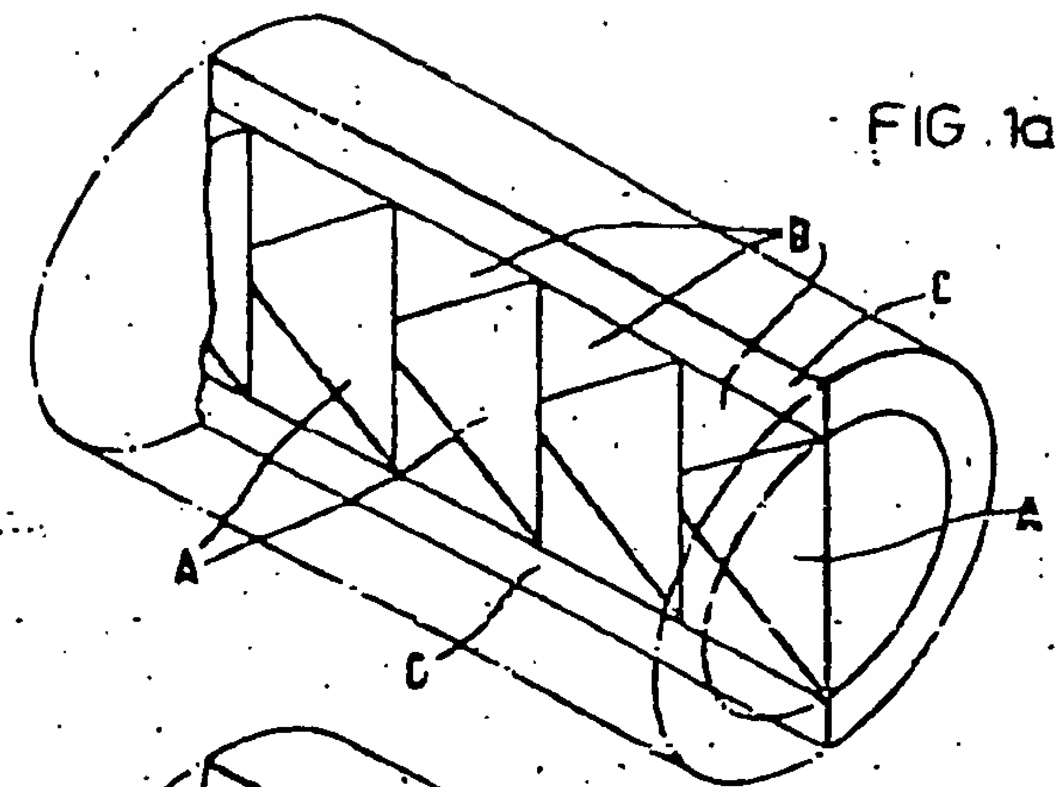

FIG. 1a.

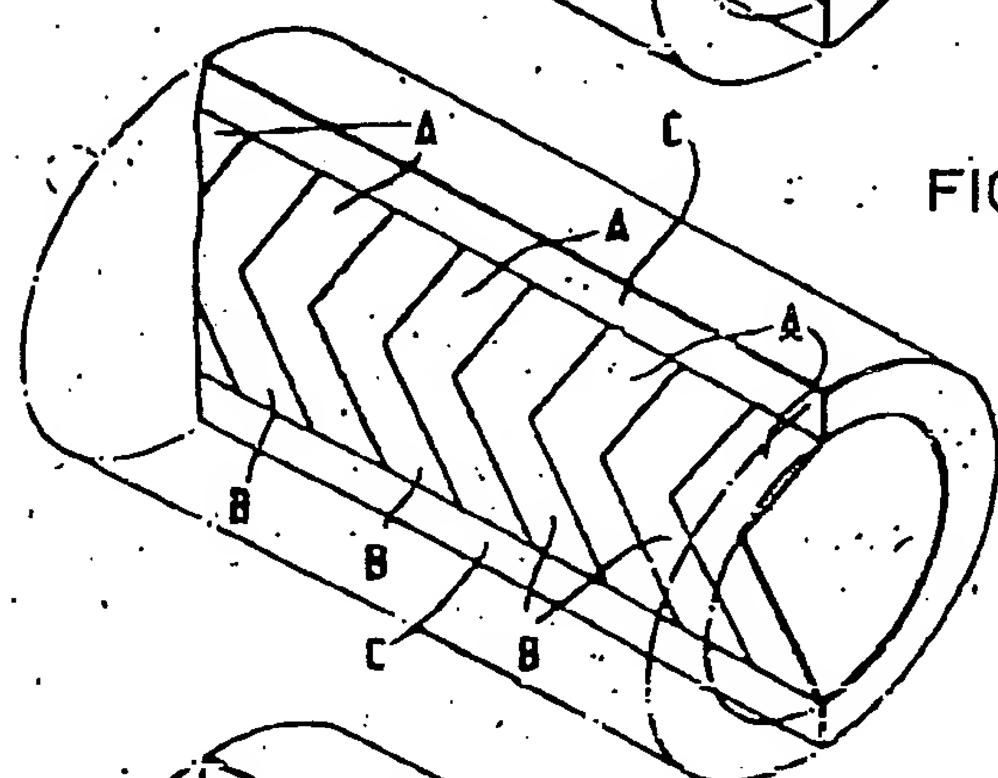

FIG. 1b.

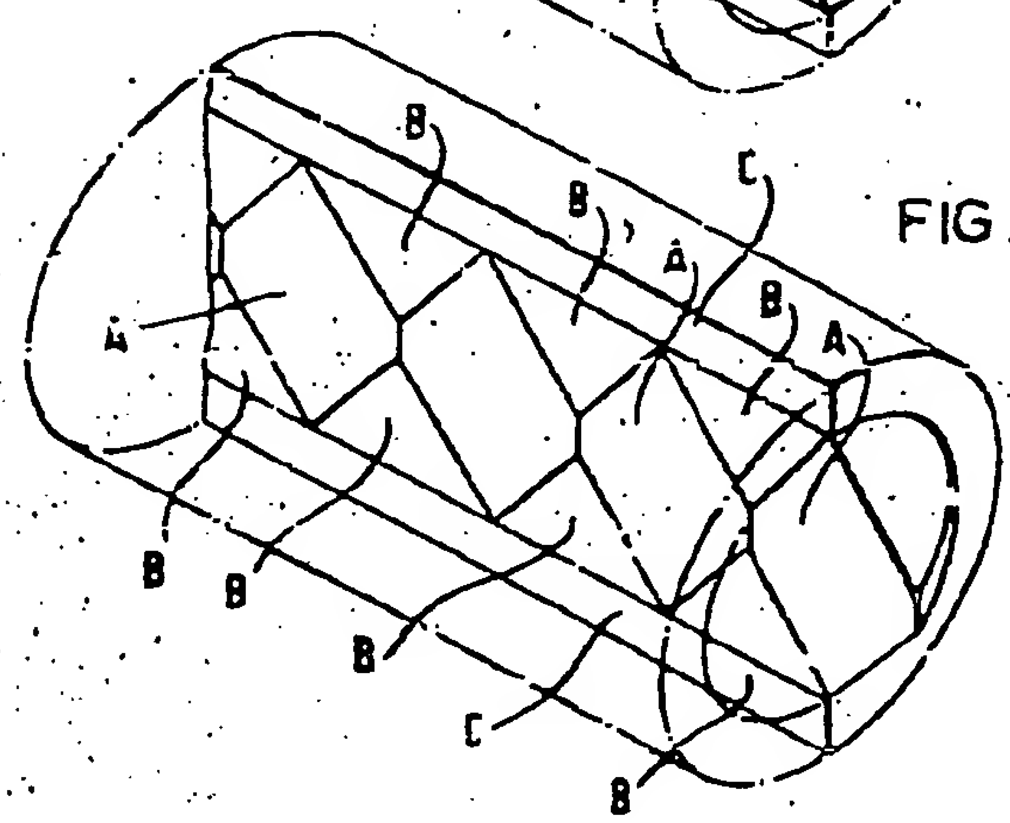

FIG. 1c.

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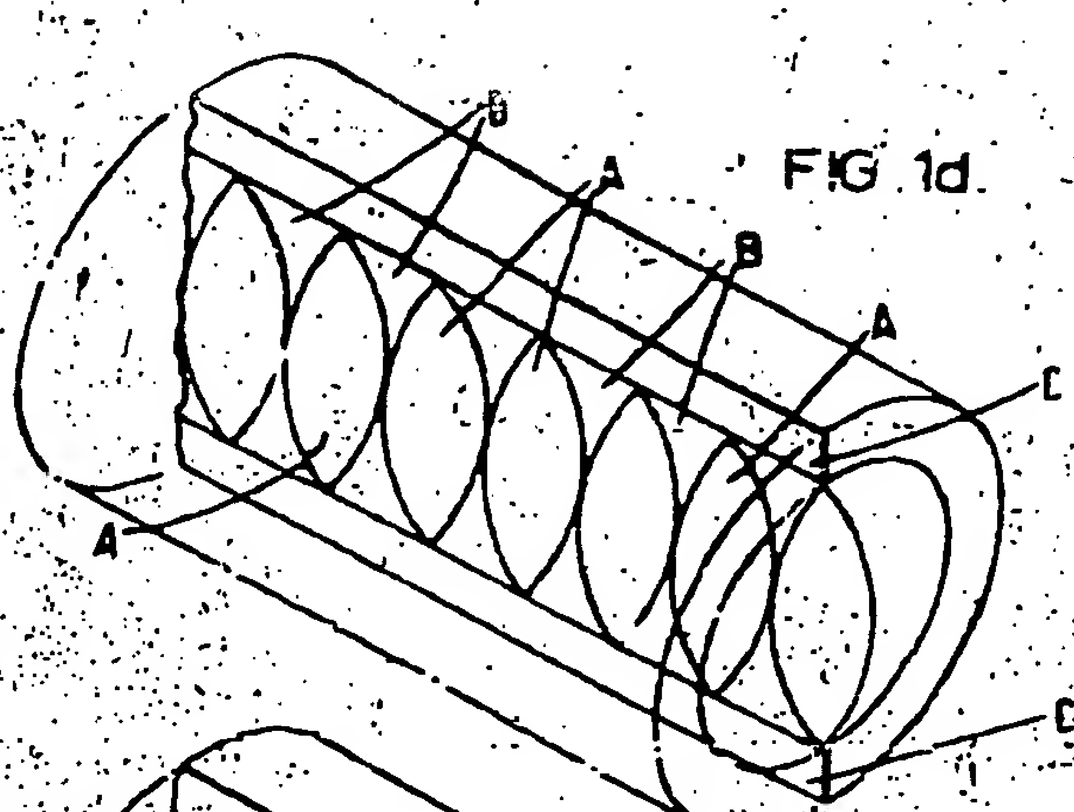

FIG 1d.

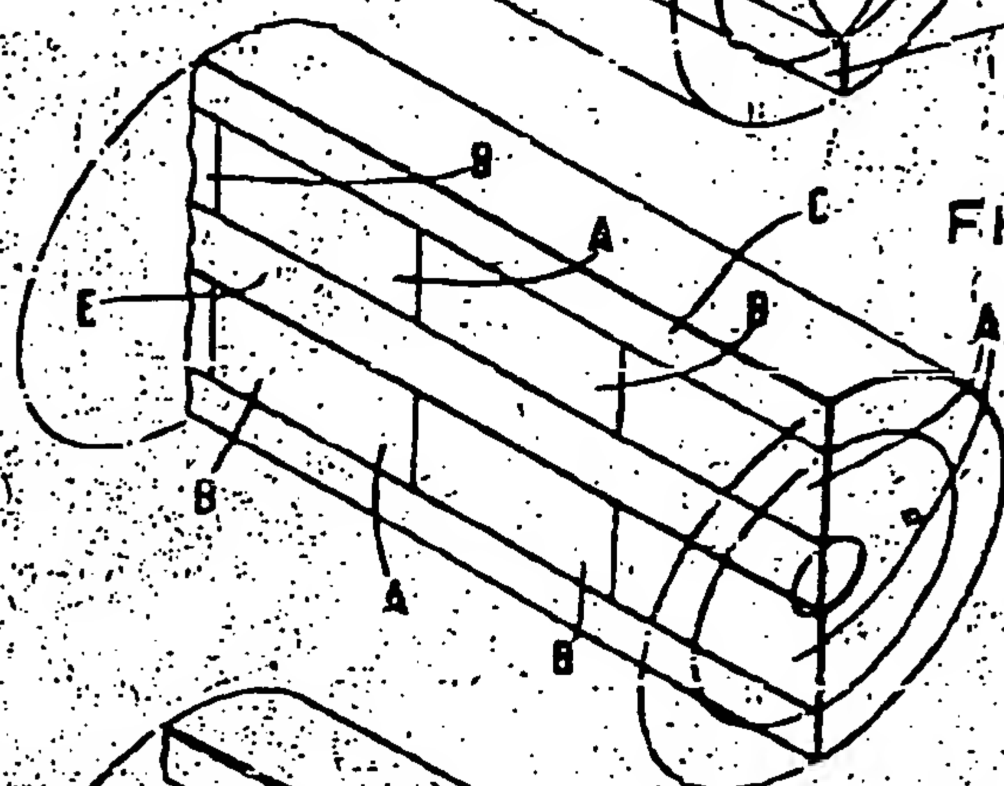

FIG. 2

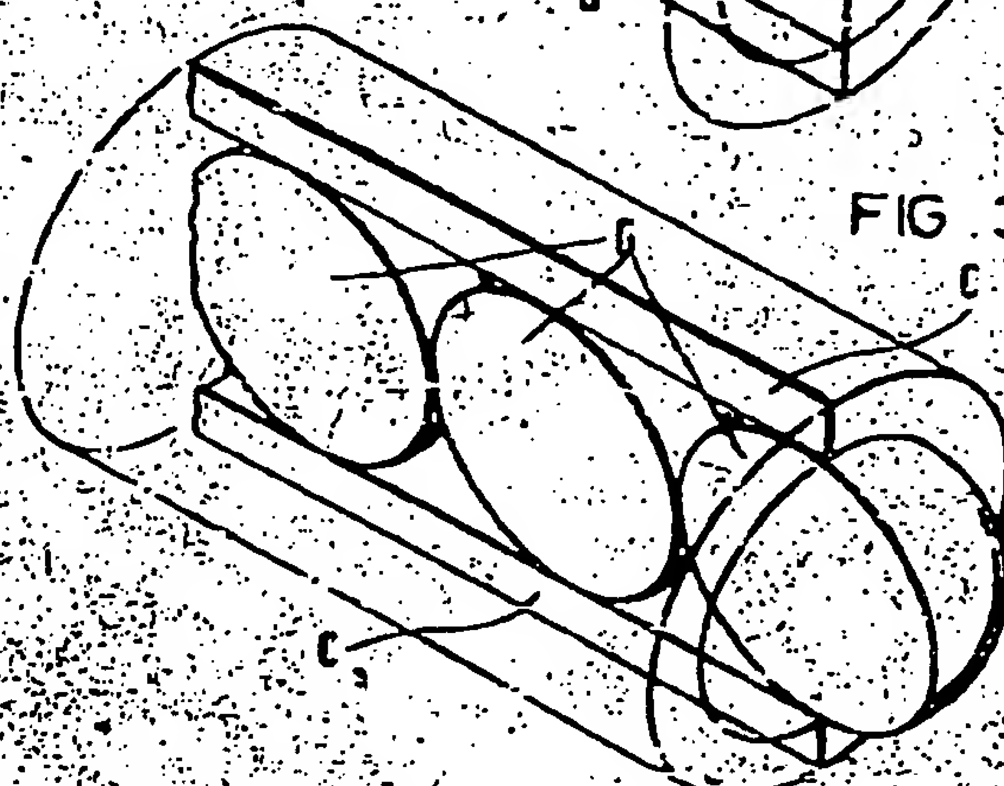

FIG 3a

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Sheet 3

FIG. 3c.

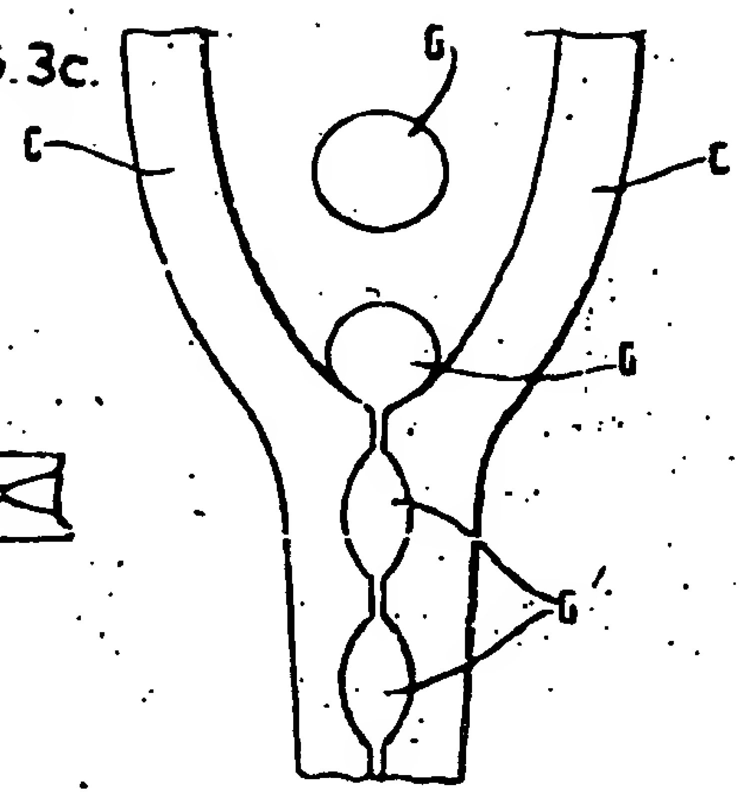


FIG. 3b.

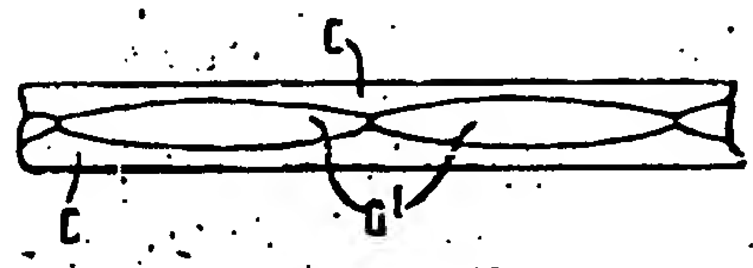
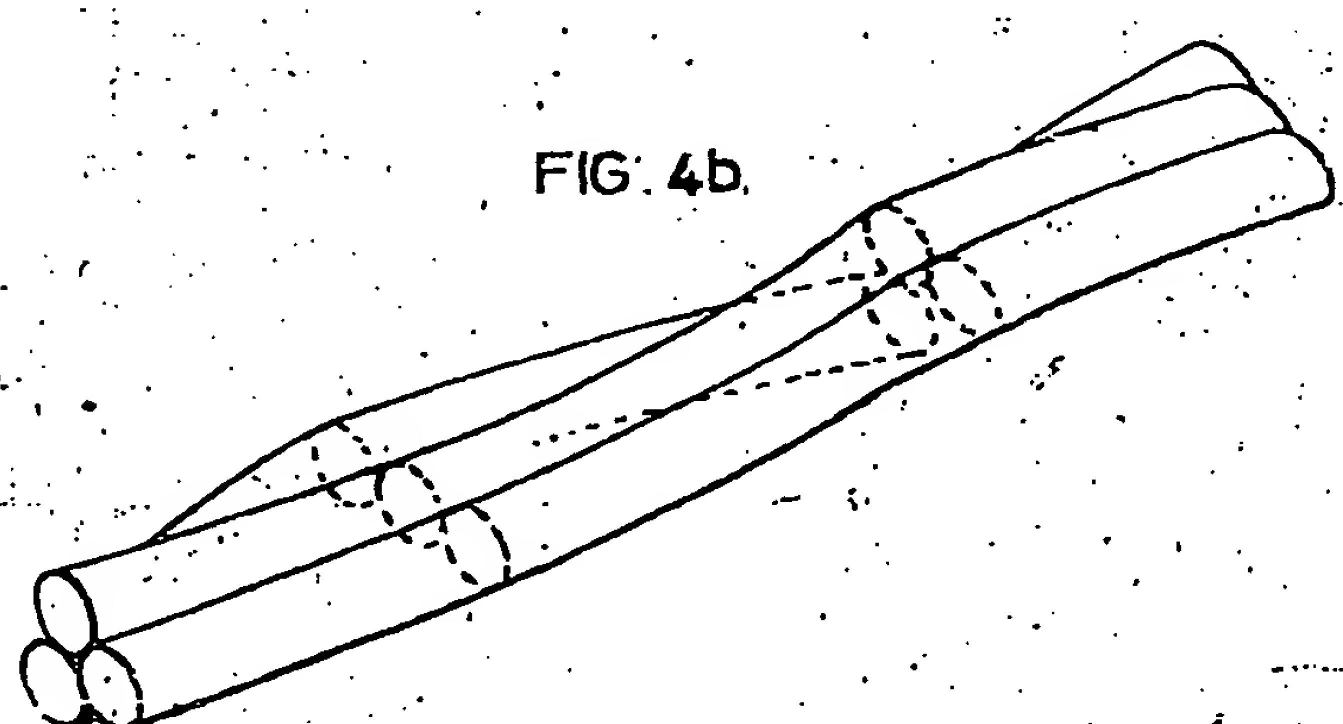


FIG. 4a

FIG. 4b.



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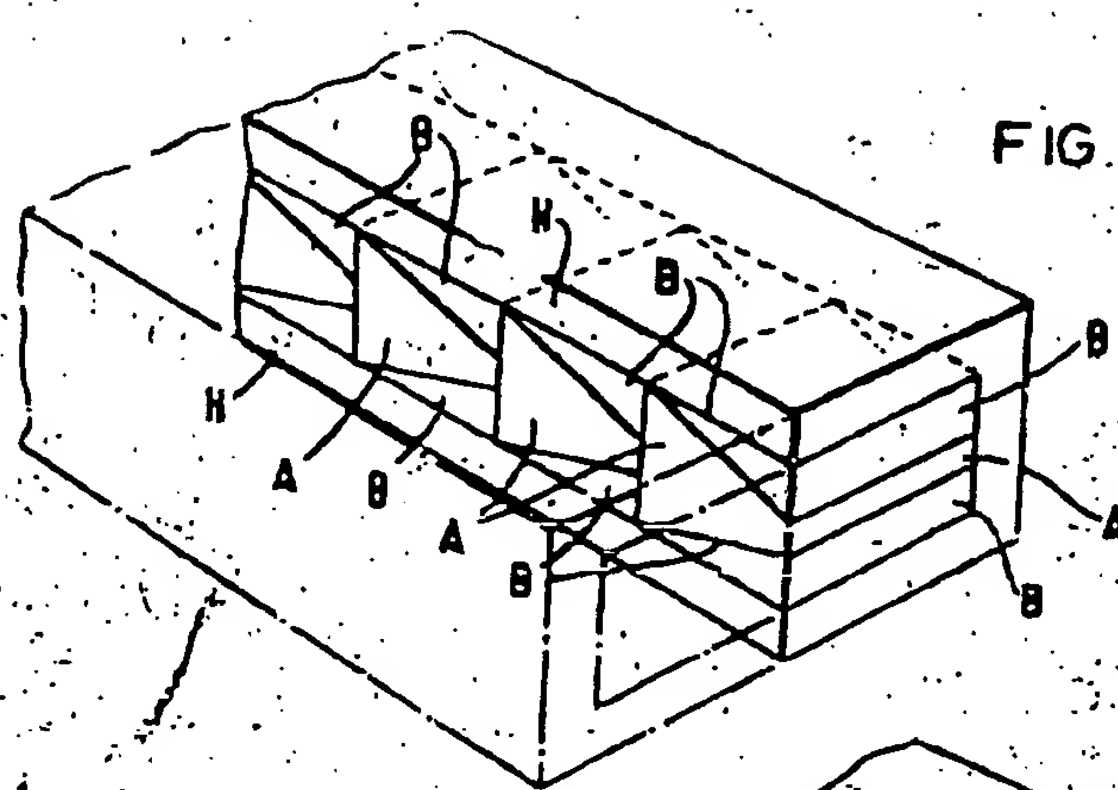

FIG. 5a.

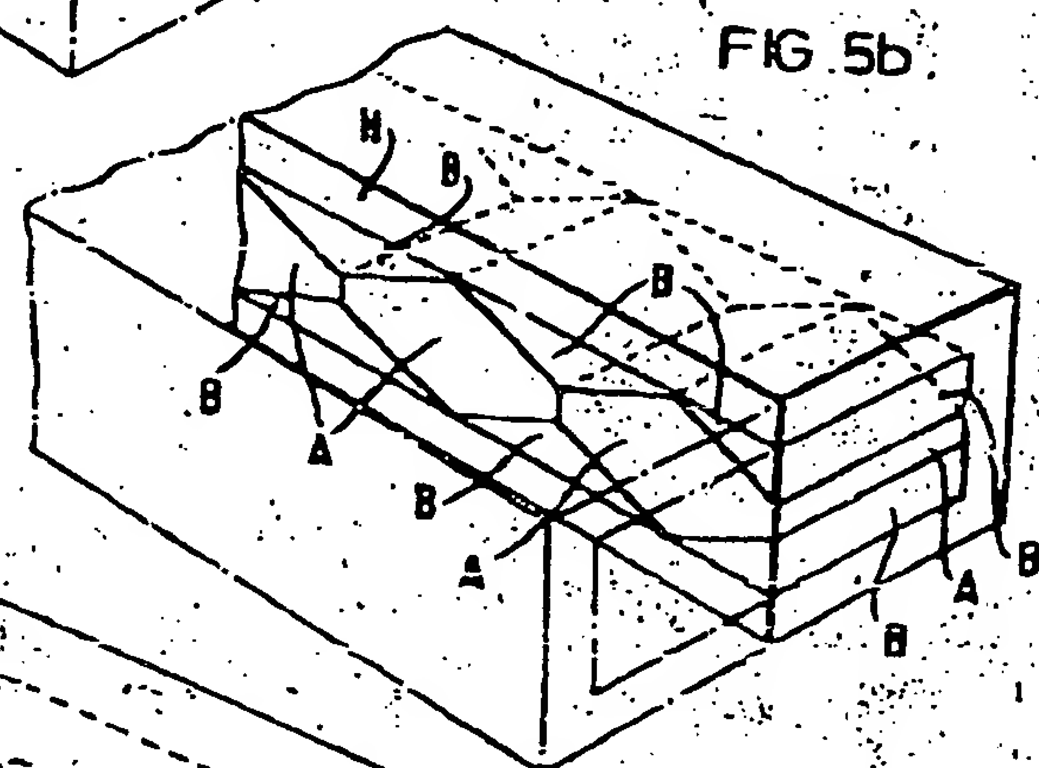

FIG. 5b.

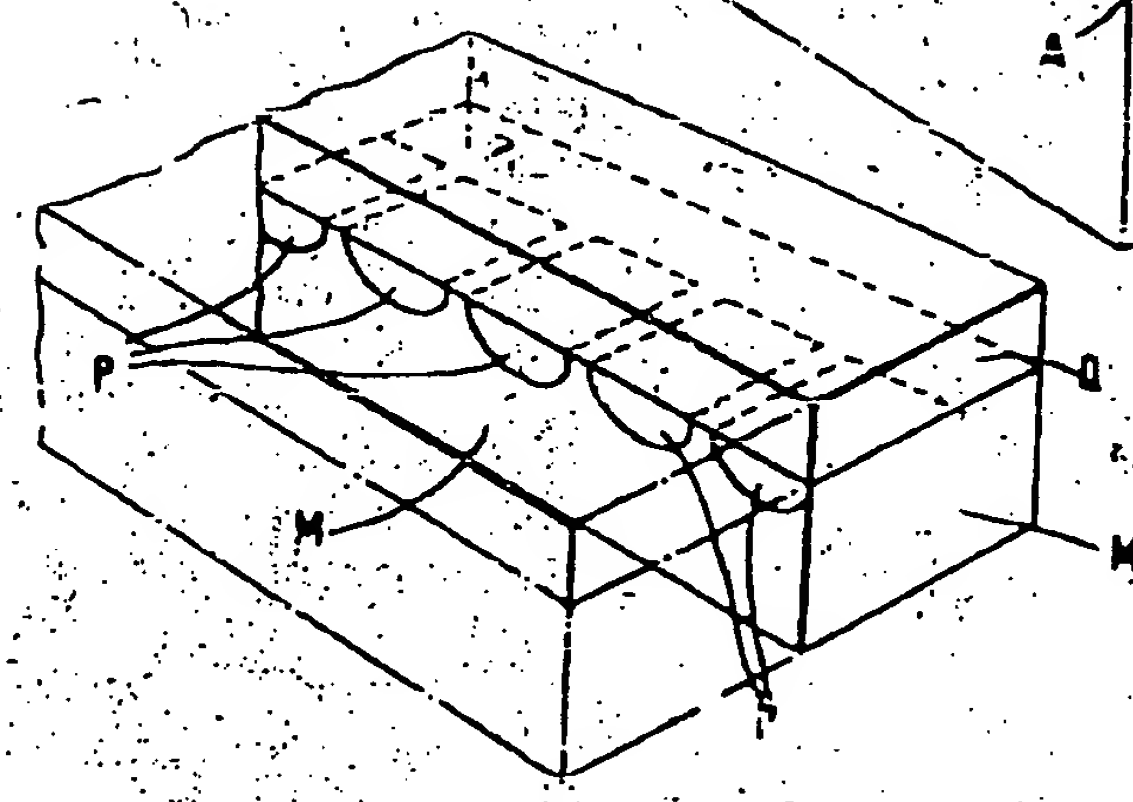

FIG. 6.

FIG 5c

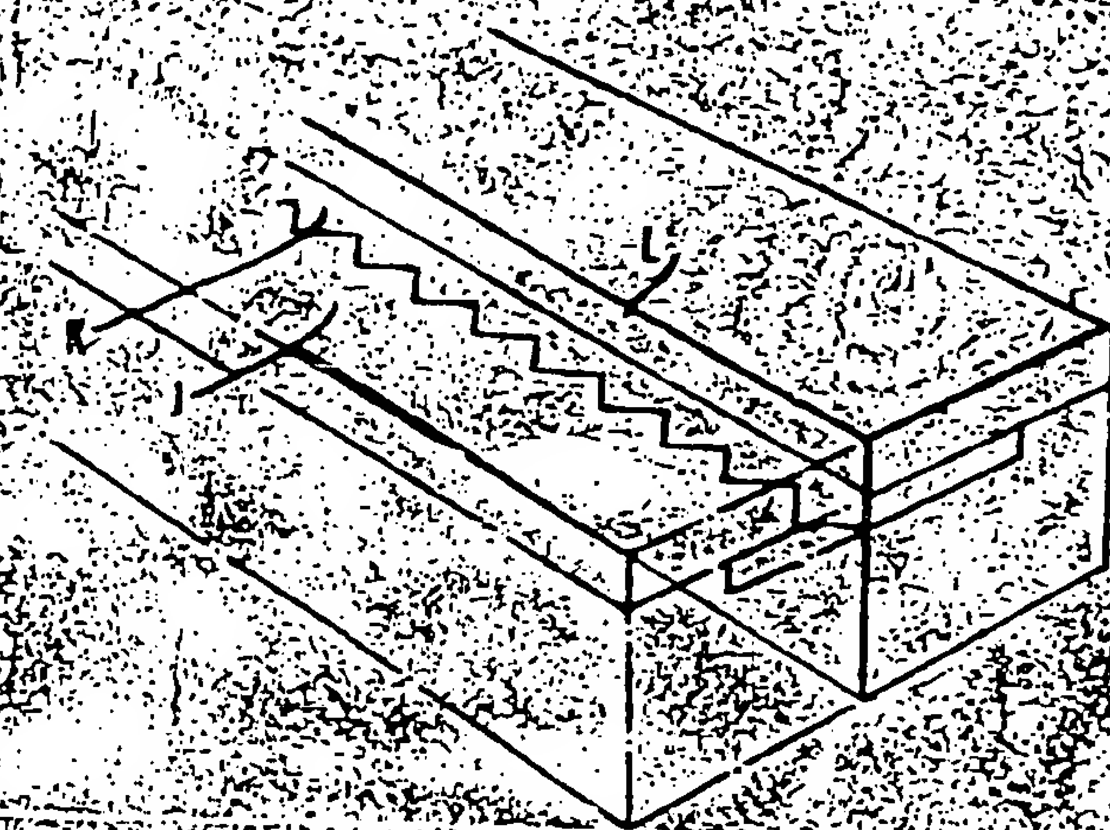

FIG 5d

FIG 5e

FIG. 7a.

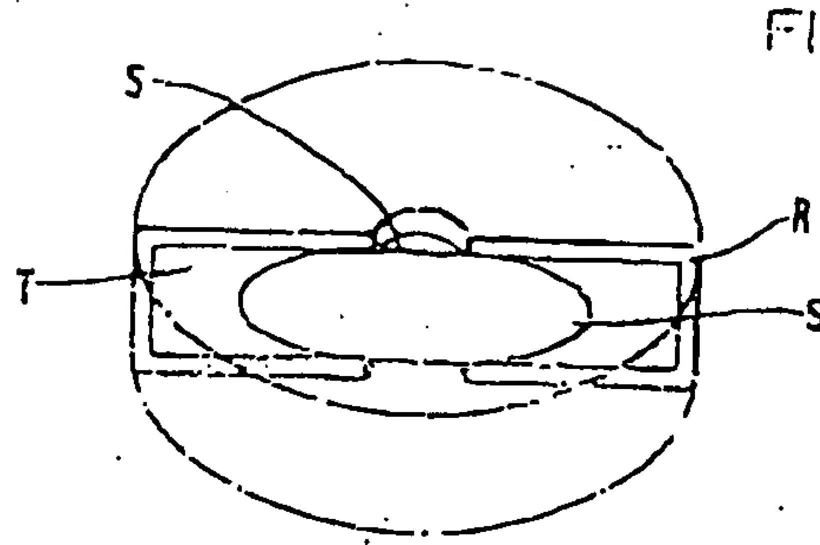

FIG. 7b.

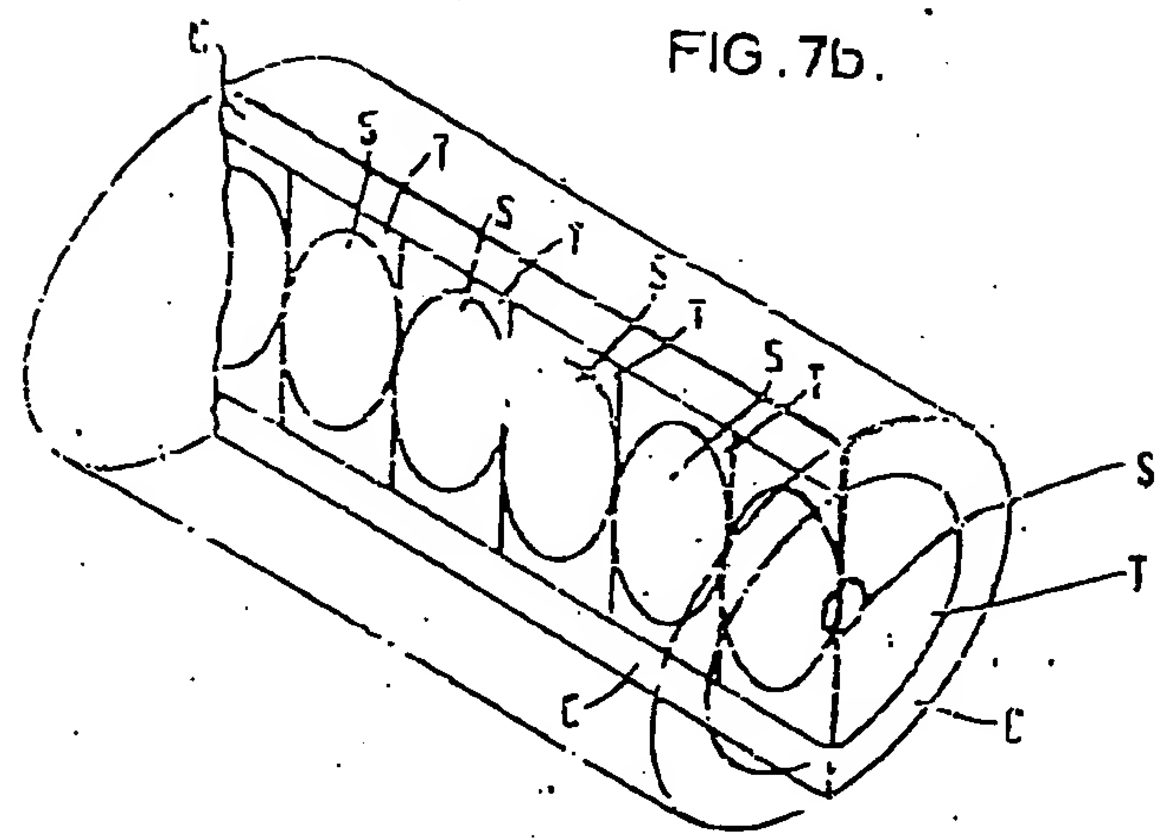

FIG. 8a.

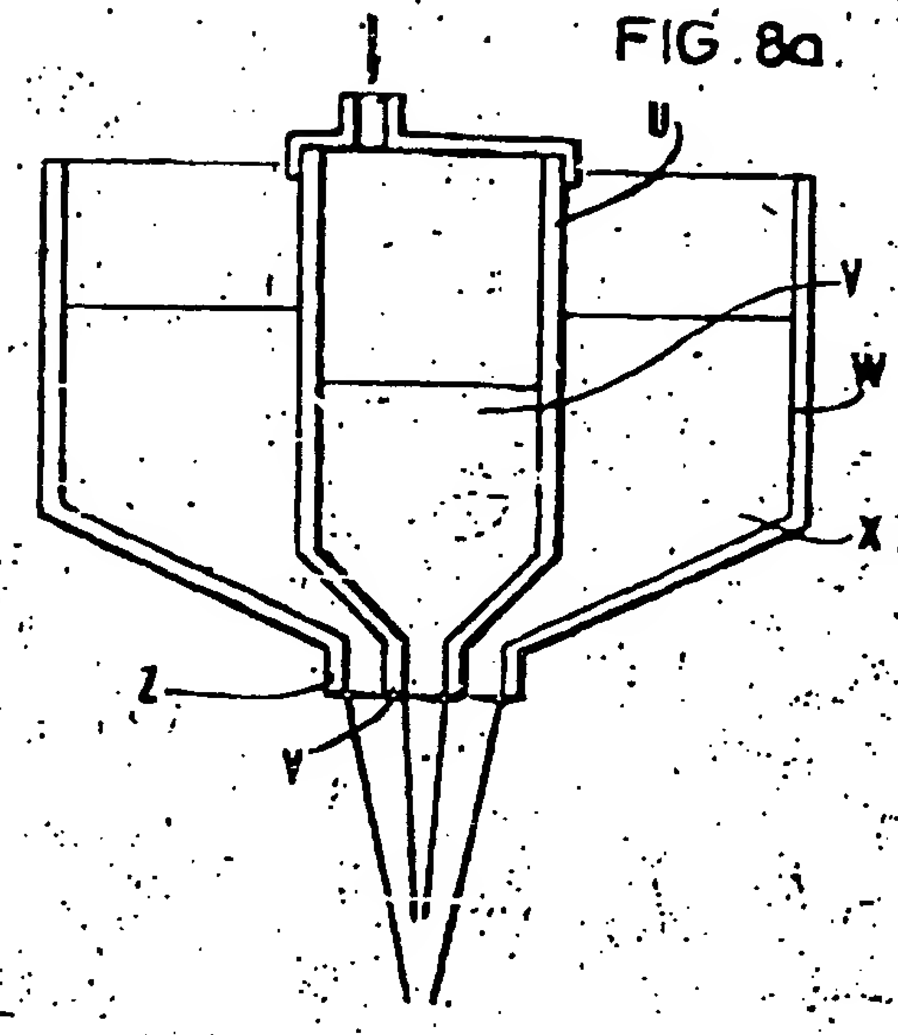

FIG. 8b.